



CONSTELLATION

Strategies for Ground Based Testing of Manned Lunar Surface Systems

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Presentation Outline

- Need For Integrated Testing
- Multi-Element Integrated Test
- MEIT Testing For International Space Station Program
 - Test Configurations
 - Benefits
 - Examples of Lessons Learned
- Integrated Testing For Constellation Program
 - Proposed Configurations
- Lunar Surface Systems
 - Required Capabilities
 - Concepts for LSS Elements
 - Surface Habitation
 - Crew Mobility Chassis
 - Lunar Electric Rover
 - Power & Support Unit / Structural Support Unit
 - Portable Utility Pallet
 - Lunar Communications Terminal
 - ATHLETE
 - MEIT For Lunar Surface Systems
 - Test Configurations vs. Assembly Manifest
 - Candidate LSS MEIT Configurations
 - Typical LSS MEIT Test Configuration
 - LSS MEIT Sample Test Objectives
 - Key Strategies For LSS MEIT
- Summary



Need for Integrated Testing

- International Space Station (ISS) program presented a unique set of challenges to accomplishing ground based test and verification of space vehicle capabilities
 - First time in history a manned spacecraft could not be fully assembled and tested prior to launch
 - Elements were produced at facilities world wide and transported to orbit in a series of 30+ Space Shuttle missions spanning over ten years
 - Preliminary analysis quickly ruled out feasibility of assembling the entire station on the ground prior to launch of first elements
 - Program budgets precluded possibility of creating a 'hanger queen'
 - Many segments and modules have very closely coupled interfaces with adjoining elements
 - Consequences of a critical interface not operating properly on-orbit could be substantial
 - Performance issues and safety risks associated with returning components
 - Significant cost and schedule impacts to completion of remaining assembly sequence
- 'Ship and Shoot' was the strategy for the International Space Station Program (ISSP) during the early 1990's
 - Directly from the factory to on-orbit
 - Minimal "integration" type tests were planned at the launch site
- Before the end of that decade a shift in testing strategy occurred within the ISSP
 - Integrated approach for ground validation
 - Availability of related subsets of elements at the same time and place
 - Criticality of on-orbit functionality and safety concerns for the crew

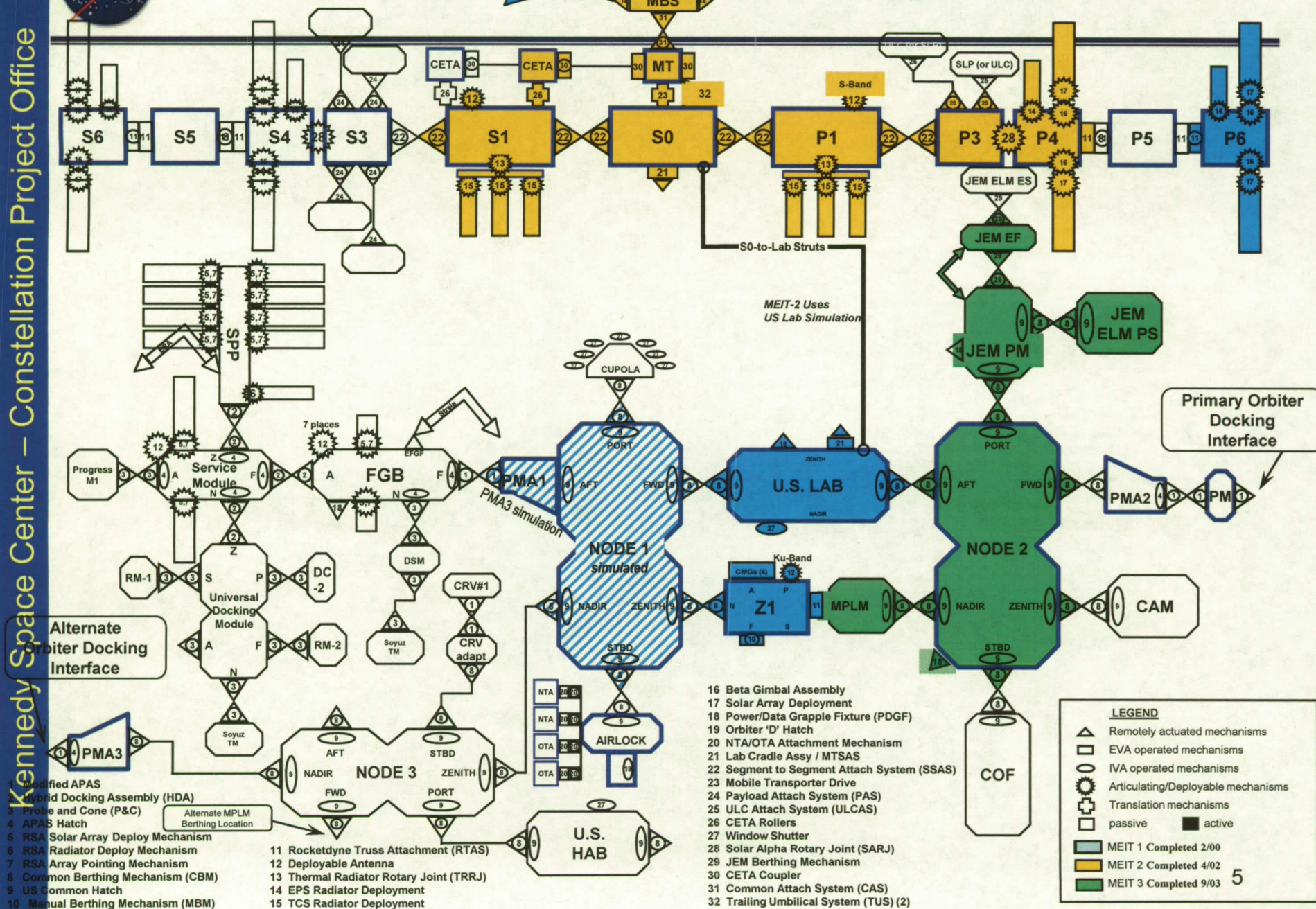


Multi-Element Integrated Test

- An integration test between two or more flight elements that will be launched on separate launch vehicles and integrated together for the first time in space. Interfaces between the flight elements, ground segments, and other appropriate program organizations may be also tested as part of each MEIT
- Assumptions
 - Production flight elements used for test
 - All inter-element interfaces have already completed formal verification
 - Checkout of both nominal and primary contingency capabilities needed for safety critical functions
 - Utilize crew/mission operational procedures to establish test objectives and configurations
 - Demonstrates on-orbit scenarios utilizing flight-like procedures
 - Performed post-turnover to KSC Ground Operations at approximately L-6 months from first crewed mission (Orion-2)
 - Utilizes fully qualified software for testing
- Objectives
 - Demonstrate and validate inter-element interface compatibility and function interoperability
 - Provides final validation of flight-like and on-orbit procedures against the actual flight hardware (Test Like You Fly)
 - Serves as a risk mitigation effort to test above and beyond individual system level acceptance testing

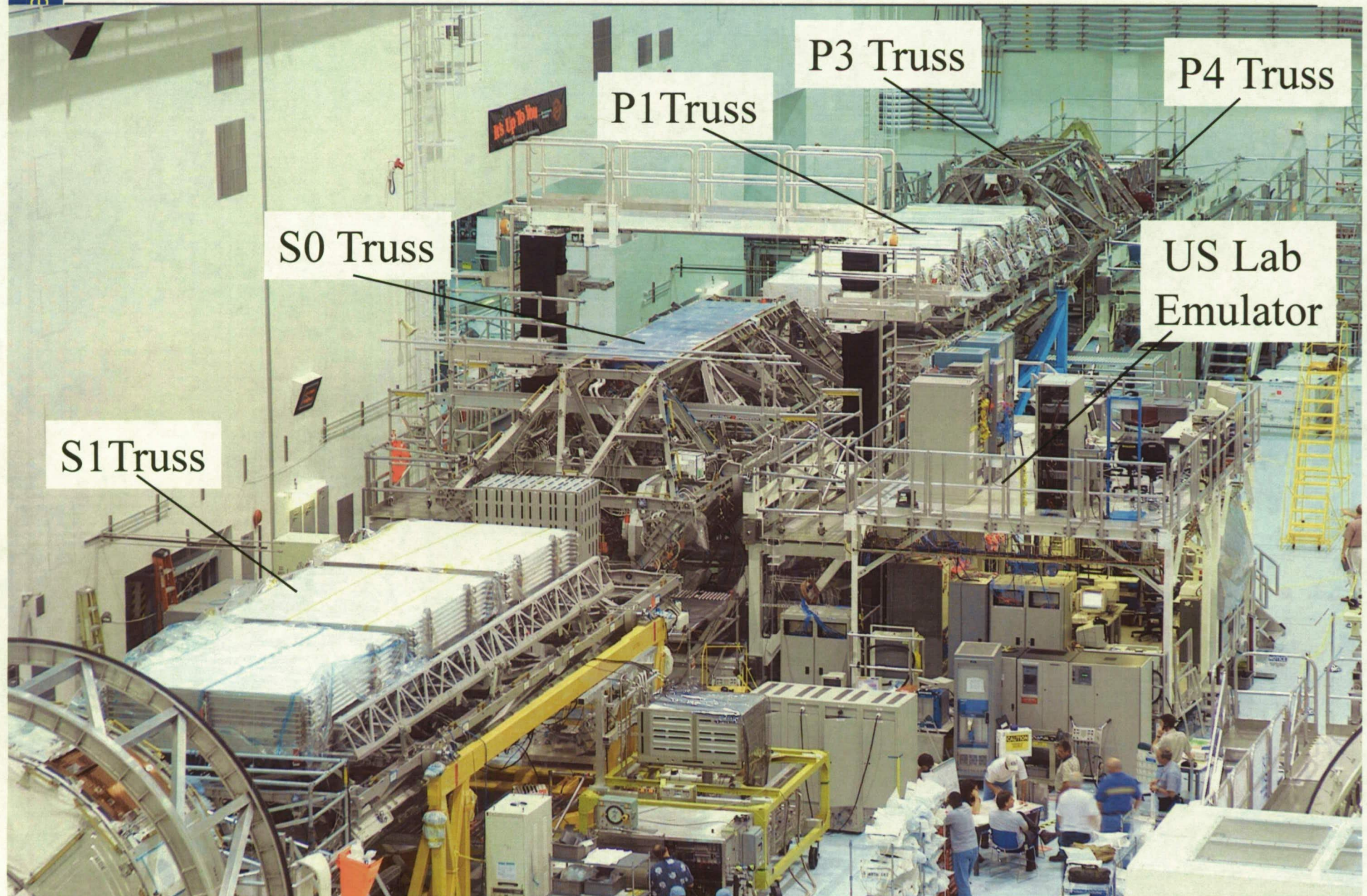
ISS MEIT

Configurations





ISS MEIT 2 Hardware at KSC





Benefits to Performing MEIT for ISS

- MEITs at KSC ensured on-orbit success for Space Station assembly and critical flight operations
 - Identified significant problems that could only have been found in an integrated configuration with the flight hardware and flight software
 - Resolved problems that would have impacted Space Station assembly operations.
 - Many other less serious problems (software & hardware) have been fixed or had Program approved workarounds initiated before flight
- MEITs paced the development of the flight activation and checkout procedures
 - A significant number procedure deviations generated during MEIT have been incorporated into flight procedures preventing impact to on-orbit activation and checkout activities
- MEITs allowed ISS personnel to gain invaluable experience and expertise in operation, behavior, and performance of flight systems
 - Mission Operations Directorate flight controllers/Payload Flight Controllers (JSC/MSFC)
 - Station Crew
 - NASA/Contractor Systems Engineering (design vs operations)
 - International Partners



Examples of Problems Found

- Excerpt from significant findings
 - P6 failed to power up due to Auxiliary Power Converter Unit (APCU) under voltage trip condition
 - Impact: Unable to start P6 on Orbit
 - US Lab Critical Activation took 36 Hrs first MEIT Power-up (MDM/Procedure problems), Requirement <2 hrs. During MEIT regression Mission Sequence Test, Critical Activation took 1 hr, 15 minutes
 - Impact: Loss of Lab element during on-orbit activation due to thermal loading
 - C&C computers failed several times due to task overrun problems (CPU utilization problems)
 - Impact: Significant operational issues (Loss of Vehicle commanding, Vehicle health visibility, visibility to crew/ground) would occur because of continued loss of C&C MDM's
 - Video lines were swapped between Trailing Umbilical Systems 1,2 (US) and Mobile Base System (CSA)
 - Impact: Significant operational impact to manually route video signals from SSRMS to RWS. EVA would have been required to replace two harnesses to correct the problem
 - C&C failed when performing Sync to GPS time
 - Impact: Loss of accurate GPS capability, degraded attitude control capability until development /testing and on-orbit upload of new software patch
 - Quality of Space to Ground Audio was unacceptable
 - Impact: Operation and potential safety impact to crew due to lack of understanding between Crew/Ground
- Risk of not performing MEITs
 - Command path problems slowed Columbus initial on orbit activation to the point of hardware risk



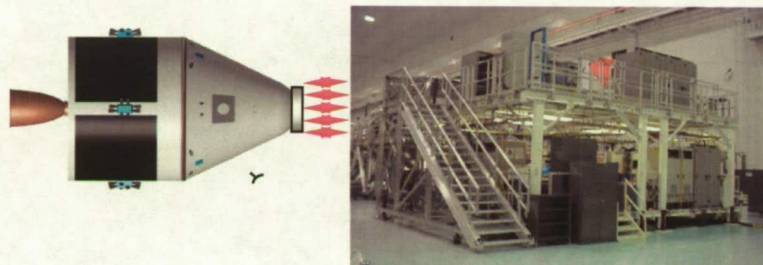
Integrated Test Planning for Constellation

- Unlike ISS, budget, schedule time and resources for early MEIT planning were first allocated early in the program (SRR timeframe) and are moving forward rapidly
 - Top level program definition documents contain requirements to perform 'MEIT-like' integrated testing on Constellation program elements
- Responsibility for integrated testing has been assigned to the Operations & Test Integration organization within the Constellation program office
 - High level concepts and requirements are documented in the Constellation Program Integrated Test Plan
- Preparations for first MEIT (Orion to ISS) are well underway
 - Overall roles, responsibilities, and strategy have been established and are agreed to
 - Test planning team has been formed with representatives from each affected organization and have been meeting for the last eight months
 - Products developed to date include preliminary test configuration drawings, high level test objectives, emulator/simulator requirements, and integration into baselined concepts for ground operation flows
- Constellation Program management fully understand and agree with the benefits of MEIT level testing and support its performance at critical points in early mission flows for risk reduction and validation of on-orbit interoperability

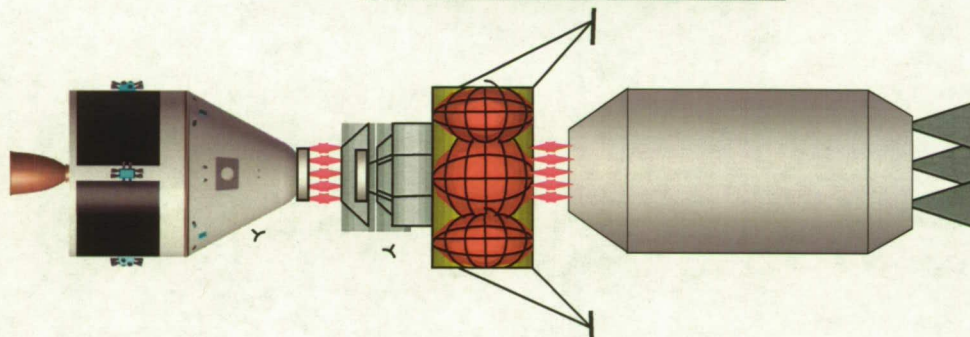


Proposed MEIT Configurations for Constellation

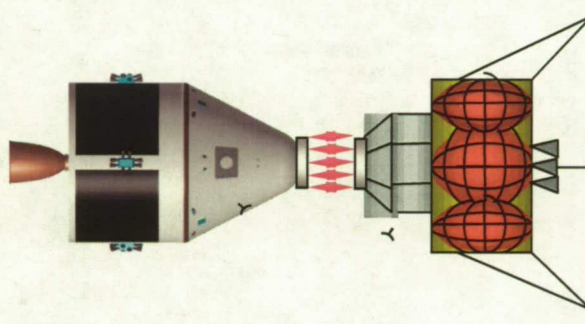
- **MEIT 1:** *
- CEV to ISS Flight Emulator



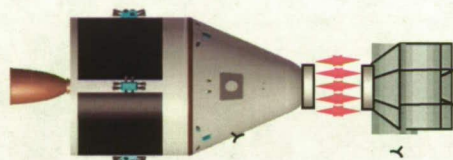
- **MEIT 2 (TC-1):**
CEV to Lunar Lander/
Earth Departure Stage



- **MEIT 2 (TC-2):**
CEV to Lunar Lander



- **MEIT 2 (TC-3):**
CEV to Lunar Lander
Accent Stage





Basic Capabilities Required for Lunar Surface Outpost

- Habitation systems that will support a crew of 4 for 180 days on the lunar surface
- Demonstrated ability to produce oxygen at a rate of 1mT per year
- Pressurized roving systems that can travel for hundreds of kilometers from the Outpost
- At least 35 kW of net power production and storage for crewed eclipse periods
- Surface based laboratory systems and instruments to meet science objectives
- Sufficient functional redundancy to ensure safety and mission success
- Caveats:
 - The Lunar Surface Systems Office is still in the stage of formulating and analyzing various architectures.
 - All concepts and illustrations are notional; there has been no selection of a 'baseline' architecture at this time.

LSS Element Concepts (Notional)





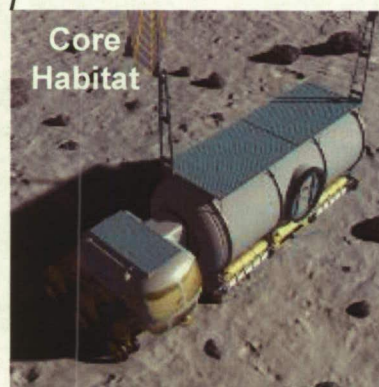
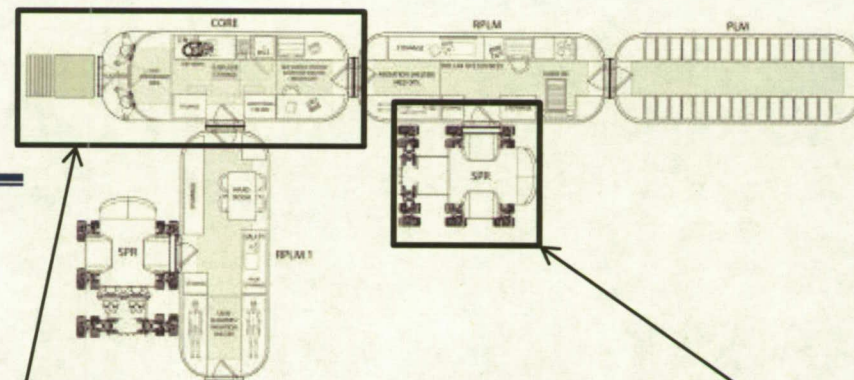
Surface Habitation

Functional Description:

The habitat elements provide a pressurized environment for the crewmembers to live and work while performing mission tasks on the lunar surface. The surface habitation main living area is comprised of a Core Habitat module which provides initial capability for 4 crew staying for up to 28 days. With the addition of 2 Reusable Pressurized Logistics Modules (RPLMs) which are retrofitted, and the Lunar Electric Rover (LER) crew cabins, 4 crew then have the capability to stay for up to 180 days, forming the foundation for the lunar outpost. The surface habitation elements support all aspects of IVA and EVA operations. Additionally, Disposable Pressurized Logistics Modules (DPLMs) provide IVA access to logistics supplies and spares.

Specifications:

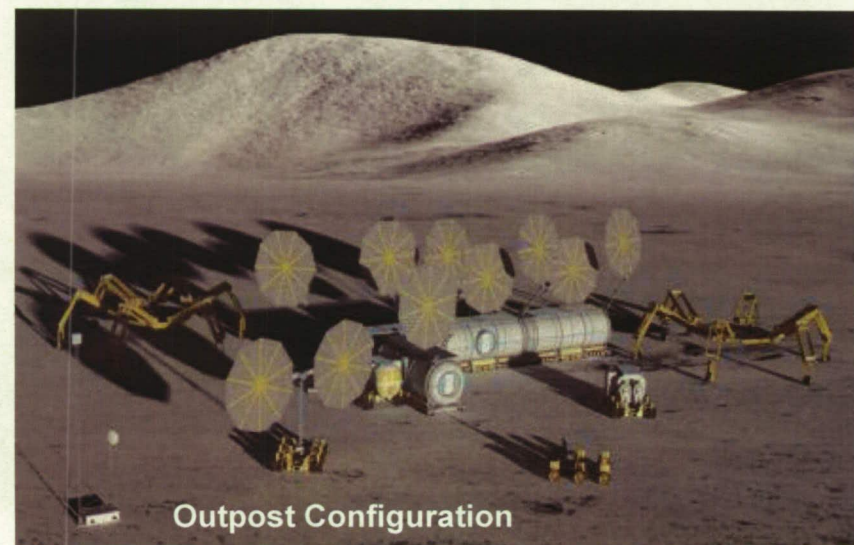
- Supports a crew of 4
- Mission duration: up to 180 days (210 with contingency)
- Al-Li hard shell module -3.0 m diameter x 8.35 m length with ~55 m³ of pressurized volume per module
- Total maximum volume = ~242 m³
- Core Habitat & RPLMs each have 3 connection ports
- DPLMs have 1 connection port
- Core Habitat has single airlock/suit lock
- Mass: Core Hab = 8.7 t; RPLM-1 = 4.3 t; RPLM-2 = 4.9 t
- Average Active Operating Power: Core Hab = 5.9 kW; RPLM-1 = 1.3 kW; RPLM-2 = 2.9 kW
- Core Habitat and RPLMs delivered with logistics to support crewed missions



Core Habitat



LER crew cabin



Outpost Configuration



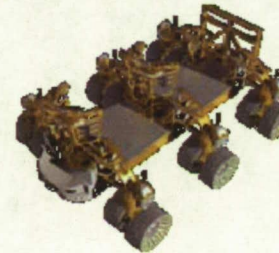
Crew Mobility Chassis (CMC)

Functional Description:

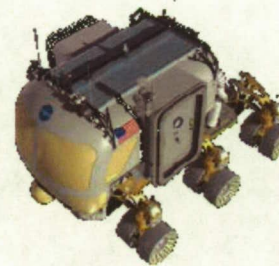
The CMC provides a mobile base for pressurized and unpressurized crew operations for up to four crew, mobile power, ISRU, and site preparation.

Specifications:

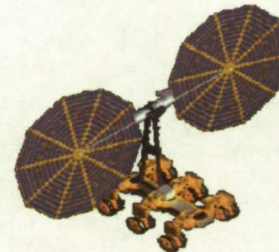
- 969 kg dry vehicle mass
- 3,000 kg payload
- >100 km range, upgradable with PUPs
- 0-5 KPH low gear, 0-20 KPH high gear
- 30°slope capability
- “Zero turning radius” crab drive
- Chassis leveling 0.75 m, +/-10 degrees
- 20 kWh onboard energy storage (Li-ion battery)
- Driven onboard or remotely supervised



CMC configured with Unpressurised Rover (UPR)



CMC configured with Lunar Electric Rover (LER)



CMC carrying Portable Utility Pallet (PUP)



CMC carrying In-Situ Resource Utilization (ISRU) payload



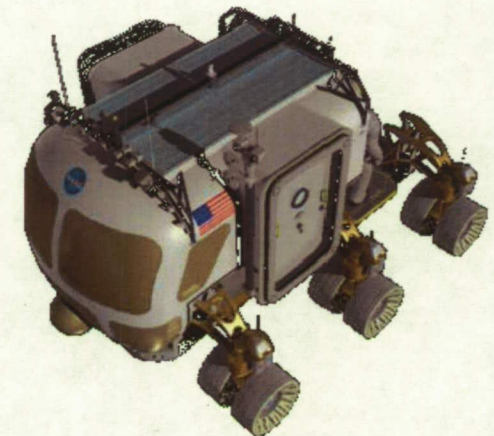
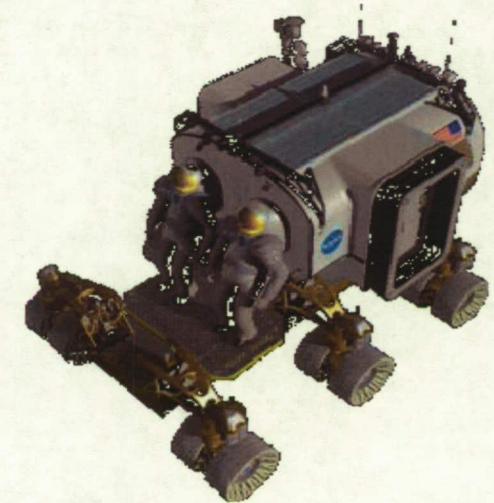
Lunar Electric Rover (LER)

Functional Description:

The Lunar Electric Rover is one concept for a Small Pressurized Rover (SPR). Each LER provides a mobile pressurized environment for a two person crew on extended exploration and scientific operations or for a four-person crew in contingencies. Comfortable shirt-sleeve, sensor augmented environment for gross translations and geological observations reduces time in EVA suit and extends exploration range and productivity. Suitports enable rapid egress to the planetary surface and rapid ingress to the shelter of the rover in emergencies while enabling significant savings in crew time and consumables. Two common hatches provide docking and transfer under pressure with habitat, logistics elements and possibly lander, which may eliminate need for a lander airlock. A fusible heat sink provides thermal management and SPE radiation protection while roving on surface. Using each other as backup, two LERs enable 2 x 2-person crews to explore up to 1000 km from the lander / outpost with additional logistics and power augmentation.

Specifications:

- Range = 100 km (3 days), 1,000 km (14 days)
- Mass = 2,952 kg (excluding chassis)
- Crew = 2 (4 in contingency)
- LER cabin pressure ~55 kPa(8 psi)
- Excursion duration = 3 days nominal extended to 14 days with Portable Utility Pallet
- EVA driving station enables operation as a UPR
- Environmental shelter protects suits while attached to suitports
- LER recharges PLSS when stowed. LER recharges ECLSS when attached to RPLM.





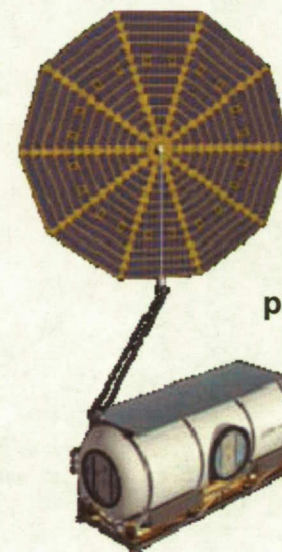
Power & Support Unit (PSU) and Structural Support Unit (SSU)

Functional Description:

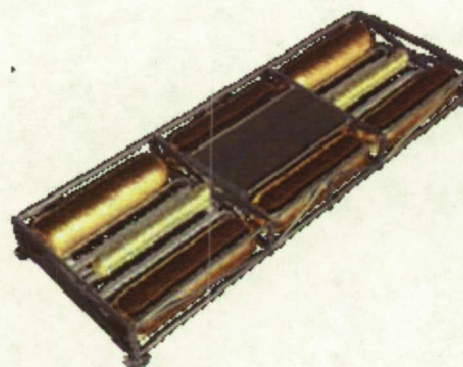
The PSU provides a support structure and launch interface for cargo elements, and it carries the RFC power system that provides solar power generation and 720 kWh of energy storage for the outpost. Also carries an avionics and communications package to support outpost, a holding tank for scavenging water from landers, and provides structure to mount Habitat ECLSS and logistics resupply tanks. The composite structure works with a pressurized module or as a stand-alone unit, and can be configured without a power system as necessary (referred to as Structural Support Unit).

Specifications:

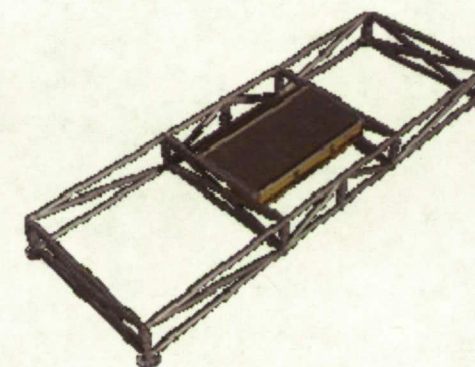
- Mass: PSU 2,867 kg / SSU 680 kg
- Energy storage
- 720 kWh Regenerative Fuel Cells
- Power generation
- 9 meter array based on Orion design
- 11.2 kW net solar array power
- Power consumables storage
- 337 kg oxygen, 43 kg hydrogen;
450 kg water x 2 (power and scavenge)



PSU with
pressurized module
and solar array



PSU without
solar array



SSU



Portable Utility Pallet (PUP)

Functional Description:

The PUP is a small logistics pallet with a solar array and batteries that provides a mobile power and consumables source for excursions in an LER. The PUP can also provide lander keep-alive power and water scavenging services. The PUP is designed to interface with the CMC during delivery to the lunar surface and on surface excursions. The PUP can also be transported on the surface using ATHLETE. Each PUP can carry the additional gas and liquid consumables to extend excursions to 14 days for 2 crew (LER nominally provides 3 days).

Specifications:

•Logistics:

- Oxygen Capacity = 25 kg
- Water Capacity = 90 kg
- Wastewater Capacity = 90 kg

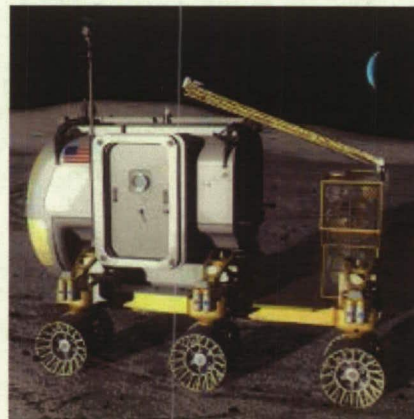
•Power Generation: 4.385 kW

- 5.5 m diameter Orion-class solar array

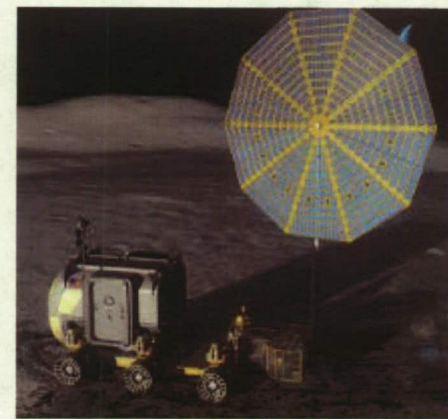
•Energy Storage: 10 kWh (Li-ion batteries)

•Mass

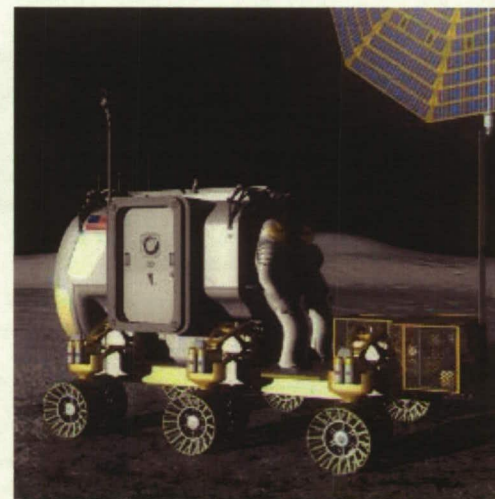
- Dry: 708.9 kg
- Wet: 963.4 kg



PUP stowed
on LER



PUP deployed



PUP attached to LER
for use during excursion



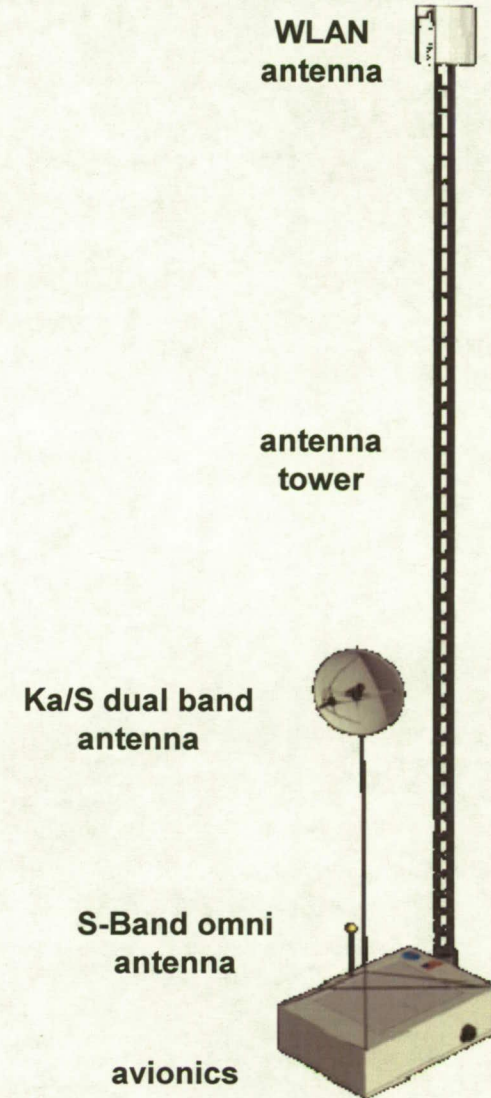
Lunar Communications Terminal (LCT)

Functional Description:

The LCT provides a communication hub for the lunar surface. The services of LCT are gateway services (low and high data rates) data delivery to Earth via Lunar Relay Satellite (LRS) (primary) or via Direct to Earth (DTE) (secondary); surface wireless services; hardwire communication; data storage; local time; and routing.

Specifications:

- 80 Mbps WLAN for lunar surface, 5.8 km range
- 200 Mbps Ka band Return Link (26 GHz) to LRS or Earth
- 100 Mbps Ka band Forward Link (23 GHz) from LRS or Earth
- 3 Mbps S-band Return Link (2.2 GHz) to LRS or Earth; 24 kbps safe mode
- 3 Mbps S-Band Forward Link (2.0 GHz) from LRS or Earth; 24 kbps safe mode
- 150 Mbps bi-directional fiber connection
- Mass: 417 kg
- Power required: 421 W (Nominal)





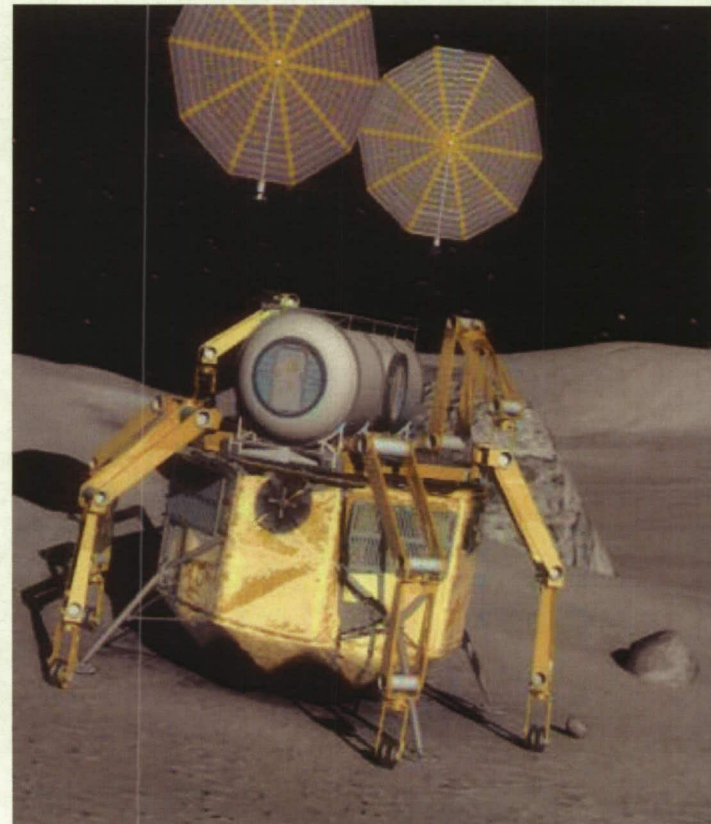
ATHLETE

Functional Description:

The All Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE) consists of two three-legged halves that combine with a PSU or SSU for offloading and long-duration excursions or with each other for operations around the outpost. Wheel-on-limbs design allows payloads to be directly 'walked' off of lander deck 6+ m high at tilts of 120 or more and over rough terrain with up to 30° slopes. When carrying a pressurized living space and sufficient power, ATHLETE enables global exploration operations.

Specifications:

- Mass: 2256 kg (complete ATHLETE)
- Payload: 14.5 t in three-legged iron cross
- Range is a function of available power
- 10 speed
- At least 30° slope capability
- 6.5 kWh onboard Li-ion battery energy storage providing
- 5km travel with max payload before recharge
- 225Wh solar array for daylight operations and battery recharge
- Driven onboard or remotely supervised





MEIT for Lunar Surface Systems



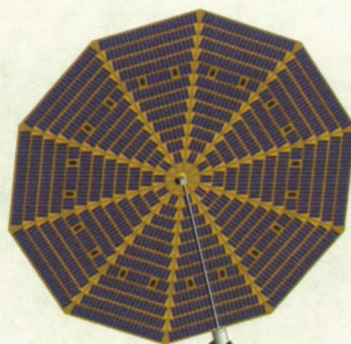
Flight hardware availability?



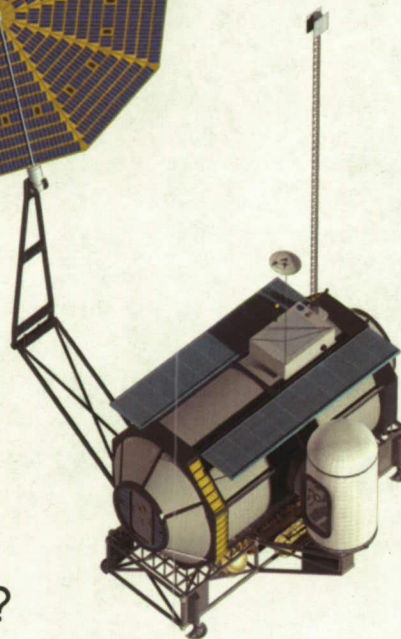
What interfaces?

Which elements?

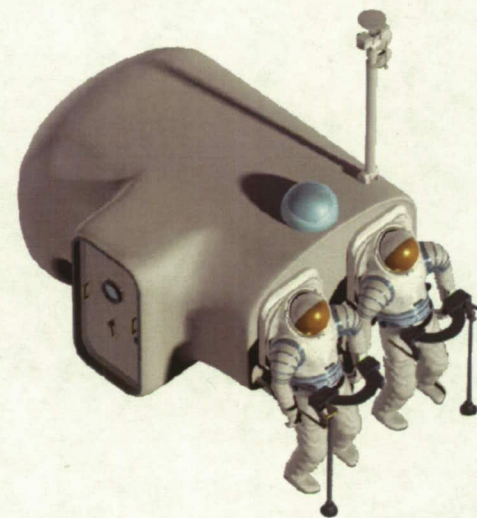
What subsystems?



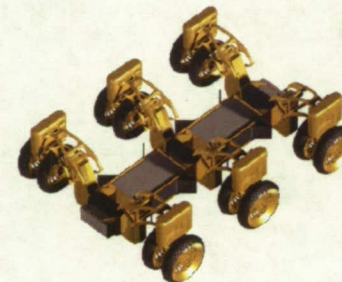
Physical mating?



Flight software availability?

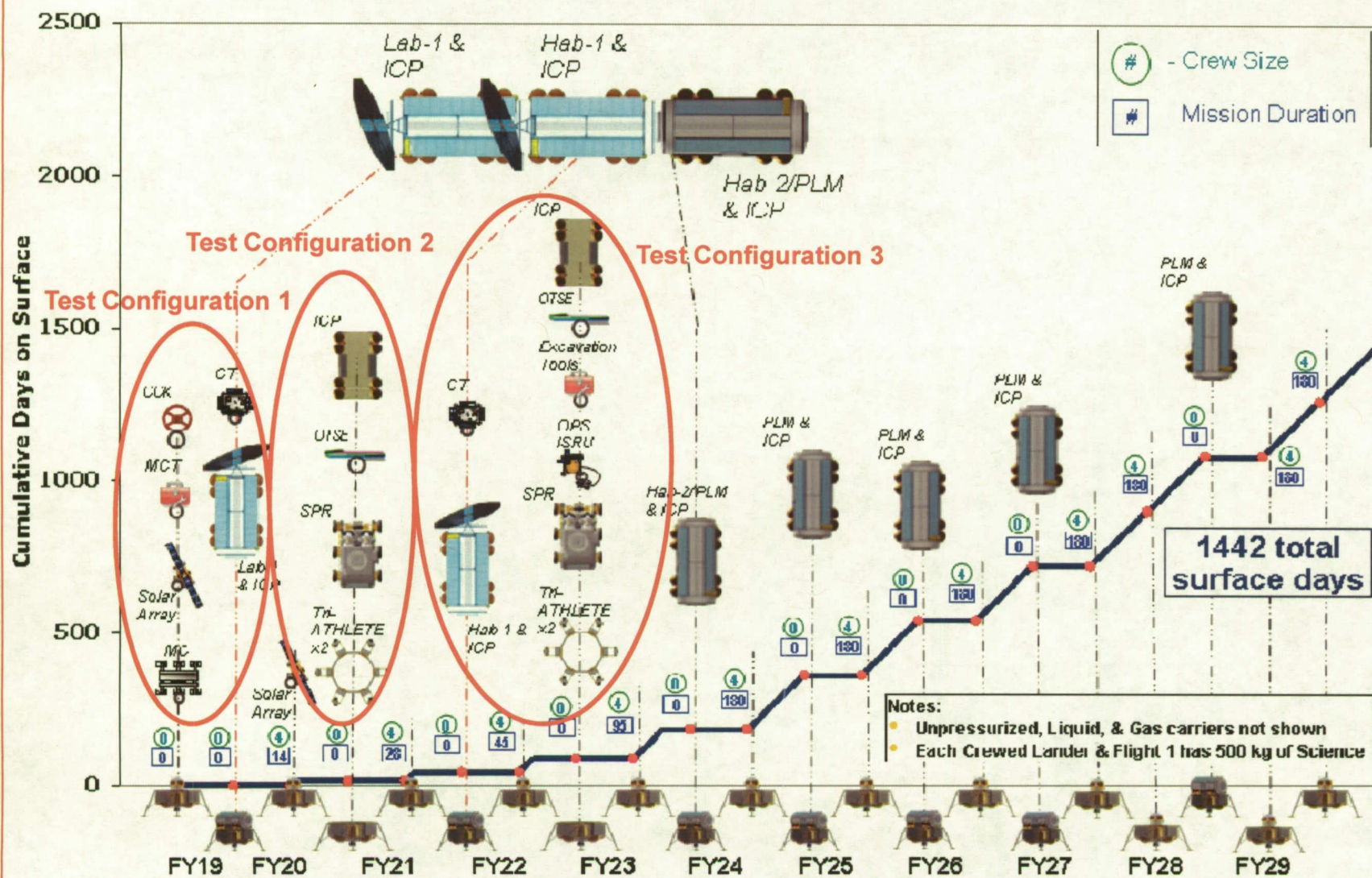


1-g support?



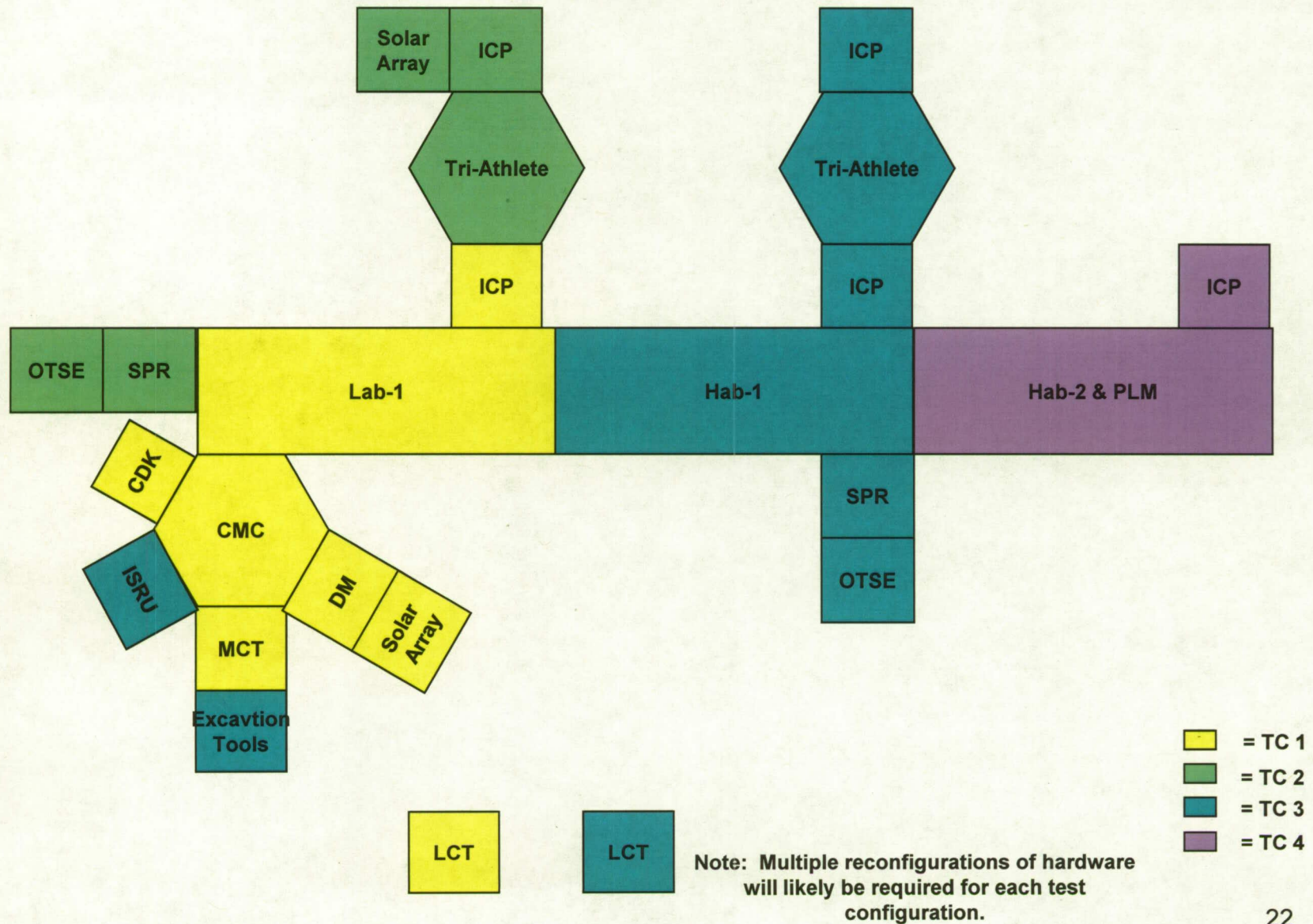


Test Configurations vs. Assembly Manifest (Notional)

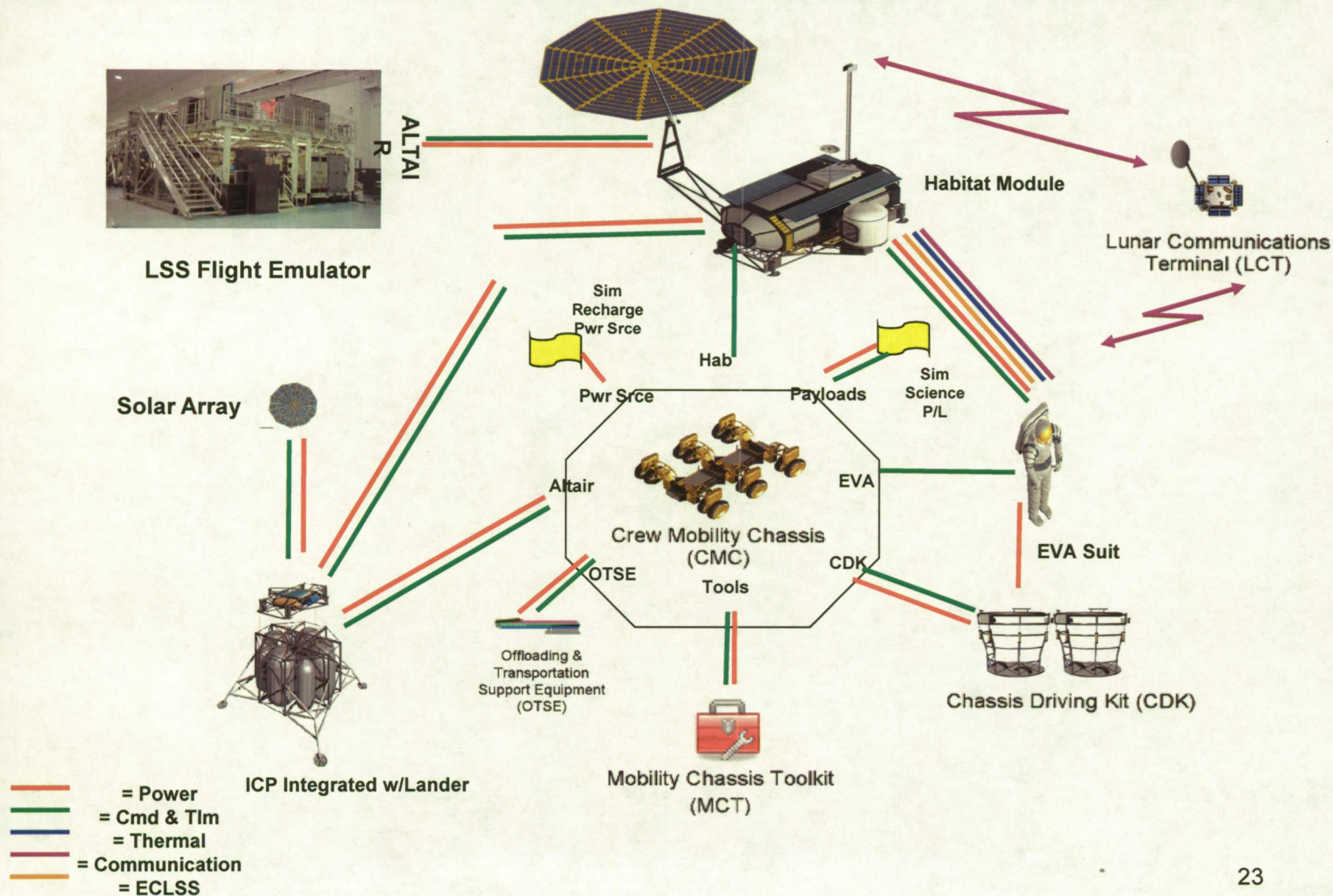




Candidate LSS MEIT Configurations (Notional)



Typical LSS MEIT Test (Notional)





LSS MEIT Sample Test Objectives

- Telemetry data reception and processing; validating end-to-end operability by demonstrating proper handling of measurement data with different message formats and content
- Proper generation, transmission, validation, and execution of commands sent from both local and remote sources across RF and hardline links
- Exercise software reconfigurations, updates, and file transfers between source and destination processors
- Demonstration of transmission and reception of audio and video signals with acceptable quality
- Power bus quality and characteristics, including verifying proper voltage and current levels between sources and loads, expected load profiles, impedance and transients measurements, etc.
- Demonstration of correct performance of selected automated fault detection, isolation, and recovery scenarios across multiple components
- Validate startup and initialization sequences and procedures from a cold start to nominal operating conditions
- Radio frequency link characterization, including validation of signal levels, bandwidth, and signal-to-noise ratios
- Characterization and validation of compatibility of thermal loads between heat sources and cooling systems



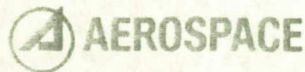
Key Strategies for LSS MEIT

- Identify needs and opportunities for integrated testing early on in program planning
- Incorporate sufficient margins are built into integrated schedules to perform testing
- Establish integrated test working groups during system definition phase with representation from all stakeholders
- Ensure adequate budgets for development and production of necessary resources are identified and built into costs baselines
- Drive capability and support requirements down into prime and sub contract language
- Participate in flight and ground system requirements and design reviews to ensure tools and resources necessary to implement integrated testing are included in baseline architecture
- Identify and plan for long lead time items, such as emulators requiring flight like or functional equivalent units, and new facilities/facility modifications
- Coordinate test planning with flight software production schedules to ensure availability of products that have completed verification and accumulated a significant amount of run time
- Make maximum use of actual ground segment capabilities for integrated testing, including Mission Control Center, SCan/NISN, TDRSS, and Deep Space Network



Summary

- Integrated testing (such as MEIT) is critical to reducing risks and minimizing problems encountered during assembly, activation, and on-orbit operation of large, complex manned spacecraft
- Provides the best implementation of 'Test Like You Fly'
- Planning for integrated testing needs to begin at the earliest stages of Program definition
- Program leadership needs to fully understand and buy in to what integrated testing is and why it needs to be performed
- As Program evolves and design and schedules mature, continually look for suitable opportunities to perform testing where enough components are together in one place at one time
- The benefits to be gained are well worth the costs - the mission you save may be your own!



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